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Short T2 tissue imaging with the Pointwise Encoding Time reduction with Radial Acquisition (PETRA) sequence: The additional value of fat saturation and subtraction in the meniscus

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ABSTRACT

Purpose: The purposes of this study were (1) to compare single-echo PETRA with dual-echo PETRA using *in vivo* MR imaging, (2) to compare non-fat-saturated PETRA with fat-saturated PETRA using a 3-T clinical MR scanner, and (3) to determine the effect of the adequate sequence and post-processing method.
Materials and methods: Twenty-two patients underwent dual-echo 3D PETRA sequence knee MR imagining (TE of 70 μs and 2.3 ms) with and without fat-saturation using a 3 T clinical MR scanner (Magnetom Trio, Siemens, Erlangen, Germany). The study population was classified into two groups: (1) normal meniscus on conventional MR images with no related physical examination on medical records and (2) meniscal degeneration or tear. We reformatted four image sets: (1) ultrashort TE signal without fat-saturation, (2) ultrashort TE signal with fat-saturation, (3) weighted-subtraction image of dual-echo PETRA images without fat-saturation, and (4) weighted-subtraction image with fat-saturation. For the weighted-subtraction images, the ultrashort TE image was rescaled relative to the second echo image with weighting factors from 0.6 based on SNR and CNR analyses. For quantitative assessment, the mean signal intensities inside user-drawn regions of interest (ROIs) were drawn and recorded. For statistical analyses, the *t*-test was used to compare the two groups and effect size was used for comparison of the discrimination power.
Results: In all image sets, the mean signal intensity values were lower in patients with meniscal degeneration/tear compared to controls on both fat-saturated and non-fat-saturated MR images. The single-echo ultrashort TE images showed higher effect sizes than the weighted-subtraction image of dual-echo images.
Conclusion: We demonstrated that there was significantly lower signal intensity on ultrashort TE PETRA images in the patients with meniscal pathologies. In addition, the single-echo of the ultrashort TE PETRA images echo time could be a more sensitive indicator between normal and pathologic meniscus conditions in patients.

1. Introduction

Ultrashort echo time (TE) magnetic resonance imaging (MRI) allows MRI to be applied to short T2 tissues, including bone, tendon, cartilage, and ligaments [1–4]. Recently, ultrashort-T2* values in the menisci had changed significantly in subjects without clinical evidence of subsurface meniscal abnormality, which suggested that ultrashort-T2* mapping is sensitive to sub-clinical meniscus degeneration [5,6]. Therefore, this technique could impact early degeneration-related findings in patients. Ultrashort TE sequence in the clinical MR scanner needs to be applied with water excitation or fat suppression to suppress longer T2 components in fat and water selectively, which may allow the anatomic structures to be identified and contributes to the high-signal-intensity appearance [7–9]. Some researchers have suggested subtraction or rescaling, i.e., weighted-subtraction, as an alternative method to direct UTE visualization [7,10,11].

Recently, it has been determined that the ultrashort TE sequence Pointwise Encoding Time reduction with Radial Acquisition (PETRA) can be performed with or without fat saturation and the shortest TE will be given by TX/RX switching time and gradient performance [12]. In the PETRA sequence, fat saturation can be added to minimize

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the effect of adjacent bone marrow or subcutaneous fat tissue. In clinical MR imagers which have limited TX/RX switching time and gradient performance, the ultrashort TE image can be utilized and applied more easily with PETRA sequence of incorporating both radial and Cartesian acquisition. Furthermore, interest in ultrashort TE sequences continues to increase as silent or quiet MR scan [13] and attenuation correction of MR/PET are required [14,15]. Therefore, we proposed that these types of ultrashort TE sequences could be utilized for short echo imaging of short T2 tissues as well as for silent or quiet MR imaging.

Meniscal degeneration and tearing are well-known cofactors in the pathogenesis of osteoarthritis [16]. To evaluate these meniscal pathologies, elevations of ultrashort-T2* values are important even in patients with subclinical meniscus degeneration [5,6]. However visualization with ultrashort-T2* imaging remains a challenge in 3-T clinical MR imaging. We thought the visualization of the short T2 tissue would be useful for early diagnosis and proper treatment of the degenerative joint disease including osteoarthritis. To our knowledge no previous studies have examined the signal intensity of the PETRA sequence in meniscal injuries. Therefore, the purposes of this study were (1) to compare single-echo PETRA with dual-echo PETRA using *in vivo* MR imaging, (2) to compare non-fat-saturated PETRA with fat-saturated PETRA using a 3-T clinical MR scanner, and (3) to determine the effect of the adequate sequence and post-processing method.

2. Materials and methods

2.1. MR imaging protocol

All MR image scans were performed at a Siemens 3 T scanner (Magnetom Trio, Siemens, Erlangen, Germany) with a maximum gradient amplitude of 40 mT/m and a maximum slew rate of 200 mT/m/ms. An eight-channel dedicated knee coil (InVivo, Gainesville, FL, USA) was used. Routine knee MRI sequence consists of T2-weighted sagittal images, T1-weighted axial images, fat-saturated T2-weighted axial images, fat-saturated T2-weighted coronal images, fat-saturated intermediated-weighted 3D SPACE isovoxel images, and PETRA sequences. The 3D PETRA sequence was set with a first echo of 70 μs and second echo of 2.3 ms. The PETRA sequence consists of a 60-μs non-selective RF pulse followed by a 40-μs transmit/receive switch time and a 100% asymmetric data acquisition from the center to the surface of a sphere. In order to achieve the shortest possible TE, data acquisition started during the ramp-up time of the readout gradient.

Typical acquisition parameters of PETRA were as follows: field of view (FOV) $225 \times 225 \times 225$ mm^3, repetition time (TR) 5.03 ms, TE 70 μs and 2.3 ms, bandwidth/pixel 540.36 Hz/Pixel, flip angle 6°, acquisition matrix $256 \times 256 \times 256$, isotropic spatial resolution $0.88 \times 0.88 \times 0.88$ mm^3, and 50,000 projection numbers (phase encoding steps) with a total scan time of 5 min and 5 s.

2.2. Study population

Twenty-two patients who underwent knee MR imaging, including dual-echo 3D PETRA sequence (TE of 70 μs and 2.3 ms) with and without fat-saturation on a 3 T MR imaging scanner between January 2012 and December 2013, were retrospectively evaluated. Inclusion criteria were: (1) patients with knee pain, (2) patients who underwent knee MRI, and (3) patients who underwent imaging with the PETRA sequence with and without fat-saturation. Thirteen patients were male and nine patients were female. The age range of the 27 patients was 20–76 years (mean age ± standard deviation, 47.1 ± 18.7 years). All of the patient information is summarized in Table 1. The study protocol was reviewed and approved by the institutional review board.

Based on the conventional knee MR findings of the medial and lateral menisci, the study population was classified into two groups: (1) normal meniscus on conventional T2-weighted/intermediate-weighted MR images with no related physical examination on medical records and (2) meniscal degeneration and tear on conventional MR images. These classifications were performed for the anterior and posterior horn of the medial and lateral menisci, respectively: MA0/MA1 (medial meniscus anterior horn), MP0/MP1 (medial meniscus posterior horn), LA0/LA1 (lateral meniscus anterior horn), and LP0/LP1 (lateral meniscus posterior horn).

2.3. Rescaled factor of subtraction 3D PETRA MRI

To calculate signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR), 8–12 mm^2 regions of interest (ROIs) were marked in the anterior horn of the medial meniscus in the normal meniscus group ($n = 17$). SNR was calculated as the ratio of the mean signal intensity inside the ROI to the standard deviation of the signal in an ROI placed in the background; this was performed at rescale factors of 0.1 to 1.0 in increments of 0.1. CNRs in the meniscus and joint fluid were calculated as the signal intensity subtraction value divided by the background noise. The CNR was highest and the SNR was most adequate at a rescale factor of 0.6.

2.4. Rescaled subtraction 3D PETRA MRI

Weighted subtraction images of 3D UTE MRI were reformatted on a separate workstation using dedicated software IDL (Interactive Data Language, ExelisVis, Boulder, CO, USA). The signal intensities of the first and second echo images were different because k-space was covered densely in the second PETRA echo. Therefore, in case of a negative subtraction value, the signal intensity of the second echo image should be adjusted before the second echo and first echo are subtracted.

$$\text{Rescaled subtraction image} = \text{UTE image} - \text{second long echo image} \times 0.6$$

2.5. Image analyses

All image sets were assessed by one musculoskeletal fellowship-trained radiologist with ten years of MR imaging experience.

Table 1
Patients summary.

No.	Sex	Age	Medial meniscus		Lateral meniscus	
			Anterior horn	Posterior horn	Anterior horn	Posterior horn
1	F	66	N	Tear	Degeneration	Degeneration
2	F	74	N	Degeneration	N	Degeneration
3	F	31	N	N	N	N
4	M	21	N	N	N	Degeneration
5	F	60	N	Degeneration	N	N
6	F	40	N	N	N	N
7	M	76	Degeneration	Degeneration	N	N
8	M	69	Tear	Tear	N	N
9	F	42	Tear	Tear	N	N
10	M	63	N	Tear	N	Degeneration
11	M	59	N	Tear	N	Tear
12	M	43	N	N	N	Degeneration
13	M	31	N	N	N	N
14	M	21	N	N	N	N
15	M	73	N	N	N	Degeneration
16	F	51	Degeneration	Degeneration	Degeneration	Degeneration
17	F	56	N	Tear	N	Degeneration
18	M	37	N	N	N	N
19	F	47	N	N	N	N
20	M	20	Tear	Tear	Tear	N
21	M	22	N	N	N	N
22	M	33	N	N	N	N

N = Normal.